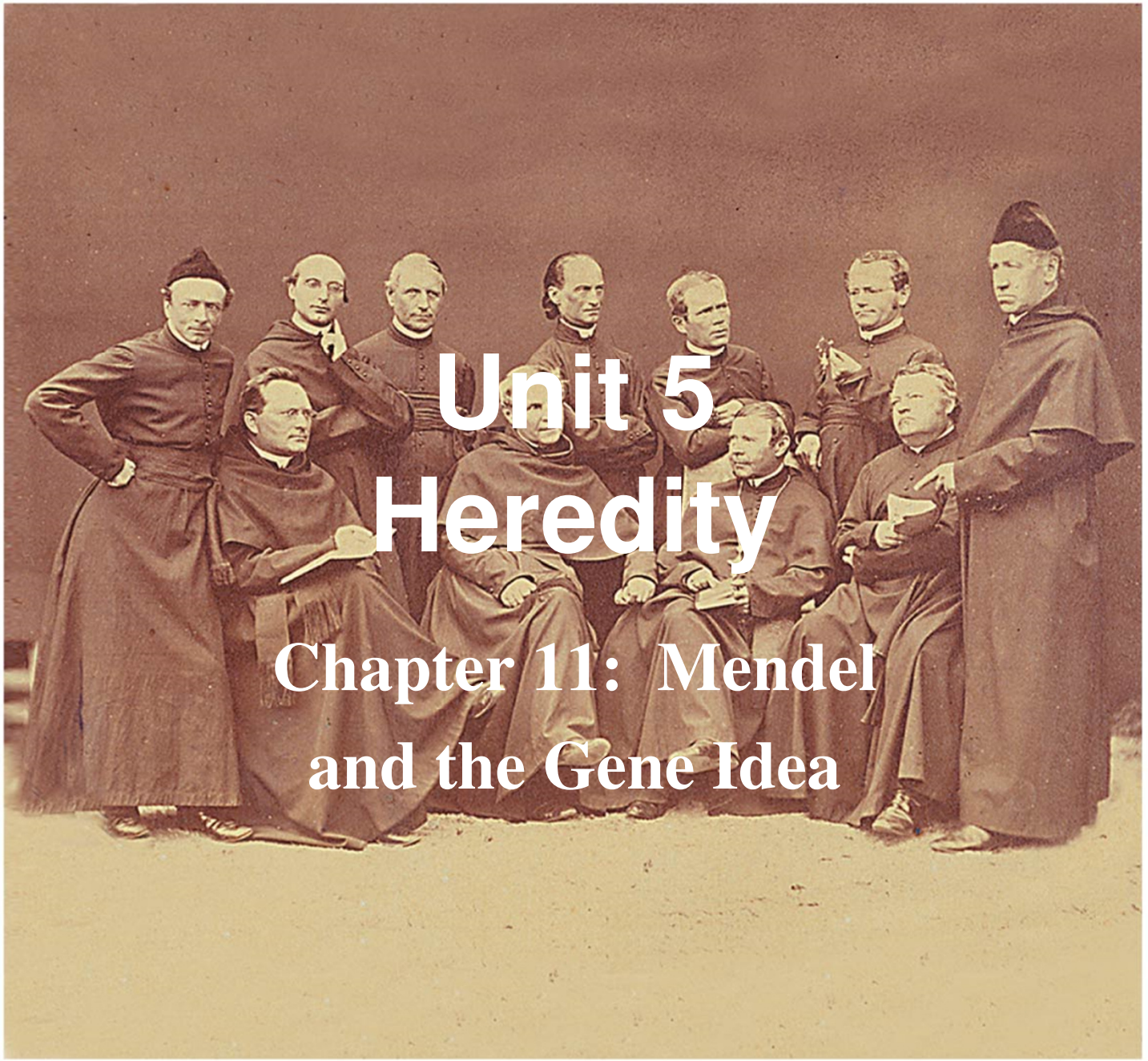


Unit 5
Heredity

Chapter 11: Mendel and the Gene Idea

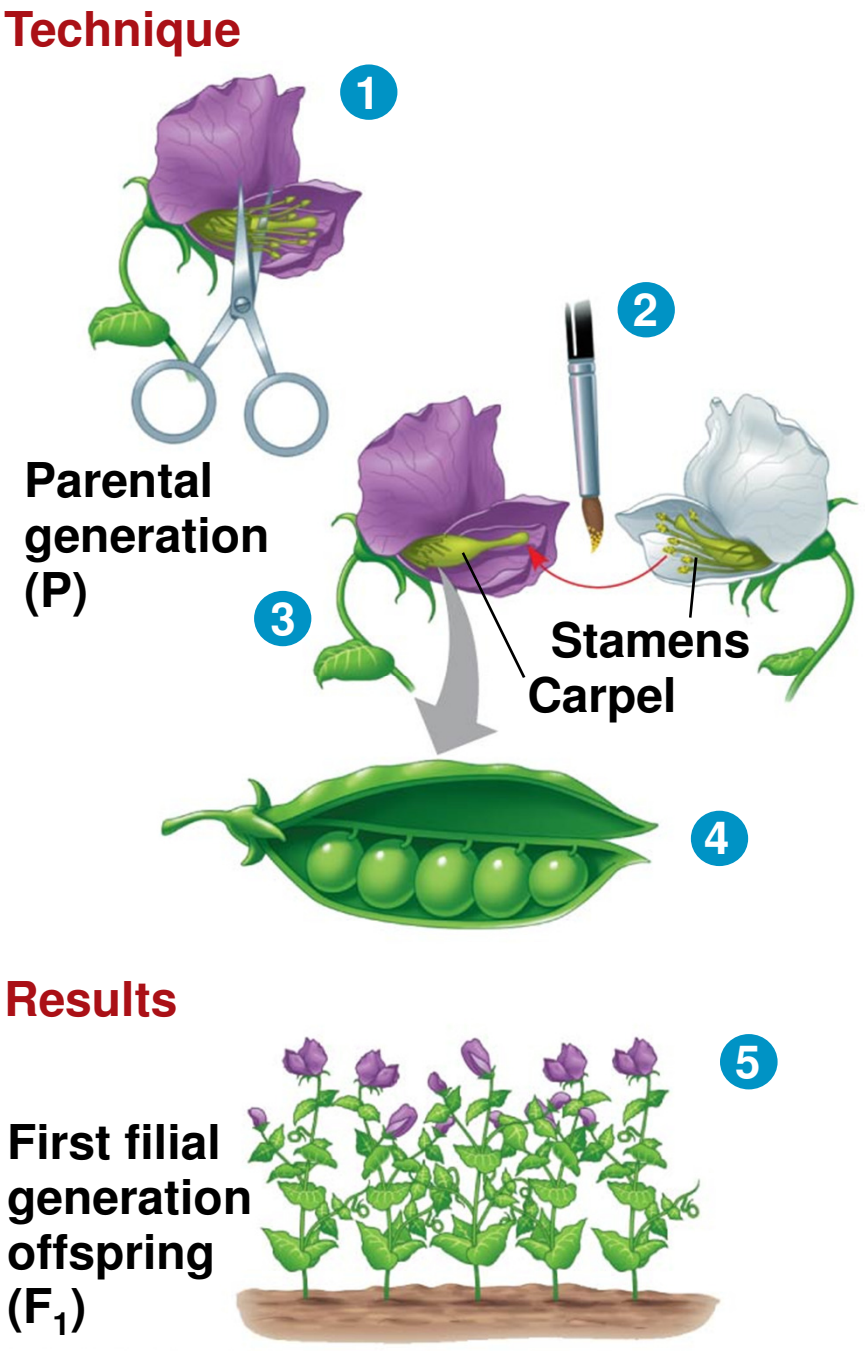
Overview: Drawing from the Deck of Genes

- What genetic principles account for the passing of traits from parents to offspring?
  - The “blending” hypothesis is the idea that genetic material from the two parents blends together (the way blue and yellow paint blend to make green)
  - The “particulate” hypothesis is the idea that parents pass on discrete heritable units (genes)
- Mendel documented a particulate mechanism through his experiments with garden peas

Concept 11.1: Mendel used the scientific approach to identify two laws of inheritance

- Mendel discovered the basic principles of heredity by breeding garden peas in carefully planned experiments
- Mendel probably chose to work with peas because
  - There are many varieties with distinct heritable features, or **characters** (such as flower color)
    - Character variants (such as purple or white flowers) are called **traits**
  - He could control mating between plants

Figure 11.2

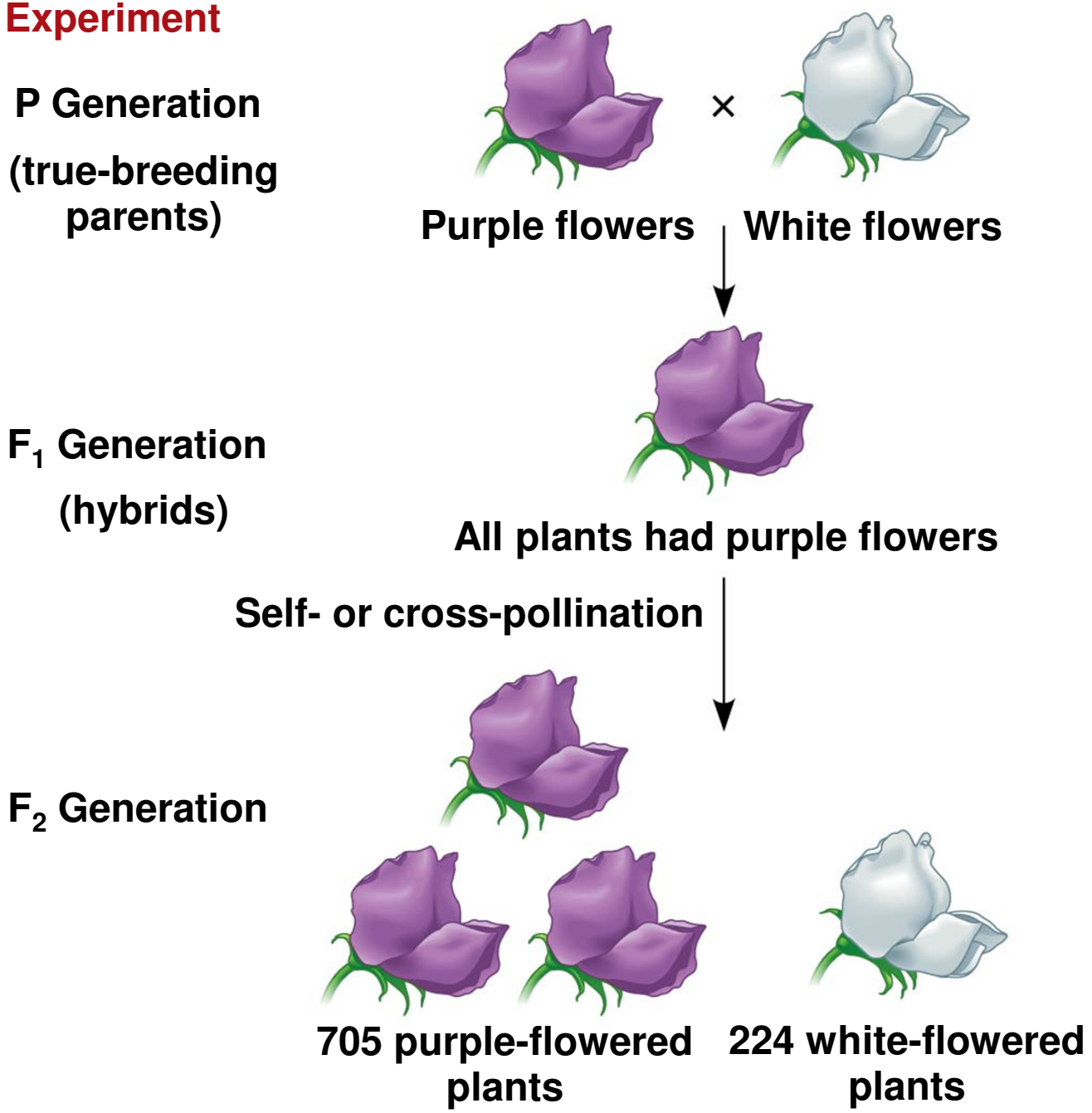

Technique
1
2
Parental generation (P)
3
Stamens
Carpel
4
Results
5
First filial generation offspring (F_1)

- Mendel chose to track only characters that occurred in two distinct alternative forms
- He also used varieties that were **true-breeding**
  - Plants that produce offspring of the same variety when they self-pollinate
- In a typical experiment, Mendel mated two contrasting, true-breeding varieties
  - A process called **hybridization**
- The true-breeding parents are the **P generation**
- The hybrid offspring of the P generation are called the **F_1 generation**
- When F_1 individuals self-pollinate or cross- pollinate with other F_1 hybrids, the **F_2 generation** is produced

The Law of Segregation

- When Mendel crossed contrasting, true-breeding white- and purple-flowered pea plants
  - All of the F_1 hybrids were purple
- When Mendel crossed the F_1 hybrids
  - Many of the F_2 plants had purple flowers, but some had white
- Mendel discovered a ratio of about three to one, purple to white flowers, in the F_2 generation

Figure 11.3-3


Experiment
P Generation
(true-breeding parents)
Purple flowers
×
White flowers
F1 Generation
(hybrids)
All plants had purple flowers
Self- or cross-pollination
F2 Generation
705 purple-flowered plants
224 white-flowered plants

- Mendel reasoned that in the F_1 plants, the heritable factor for white flowers was hidden or masked in the presence of the purple-flower factor
- He called the purple flower color a *dominant* trait and the white flower color a *recessive* trait
- The factor for white flowers was not diluted or destroyed because it reappeared in the F_2 generation
- Mendel observed the same pattern of inheritance in six other pea plant characters, each represented by two traits
- What Mendel called a “heritable factor” is what we now call a *gene*

Table 11.1

Table 11.1 The Results of Mendel's F_1 Crosses for Seven Characters in Pea Plants

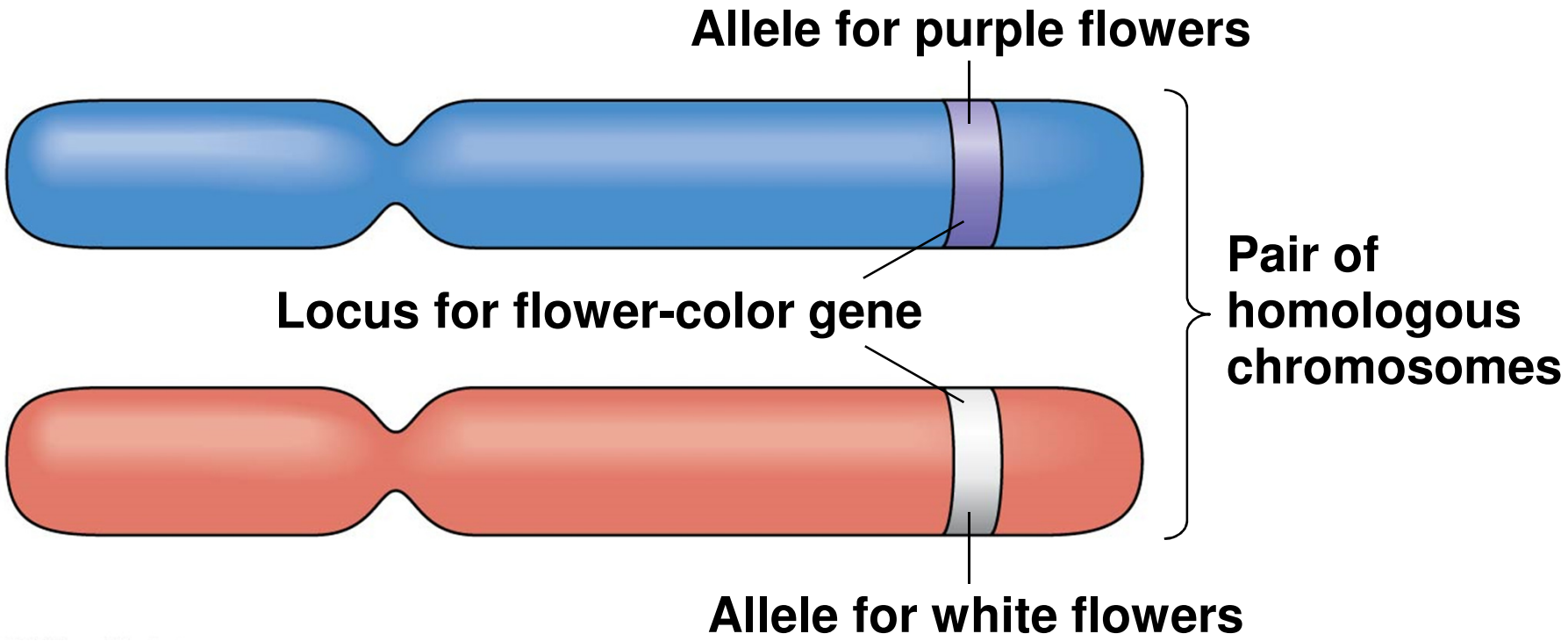
Character	Dominant Trait	×	Recessive Trait	F_2 Generation Dominant: Recessive	Ratio
Flower color	Purple 	×	White 	705:224	3.15:1
Seed color	Yellow 	×	Green 	6,022:2,001	3.01:1
Seed shape	Round 	×	Wrinkled 	5,474:1,850	2.96:1
Pod shape	Inflated 	×	Constricted 	882:299	2.95:1
Pod color	Green 	×	Yellow 	428:152	2.82:1
Flower position	Axial 	×	Terminal 	651:207	3.14:1
Stem length	Tall 	×	Dwarf 	787:277	2.84:1

Mendel's Model

- Mendel developed a model to explain the 3:1 inheritance pattern he observed in F_2 offspring
- Four related concepts make up this model

1. First, *alternative versions of genes account for variations in inherited characters*
   - For example, the gene for flower color in pea plants exists in two versions, one for purple flowers and the other for white flowers
   - These alternative versions of a gene are now called **alleles**
   - Each gene resides at a specific locus on a specific chromosome

Figure 11.4


Allele for purple flowers
Locus for flower-color gene
Pair of homologous chromosomes
Allele for white flowers

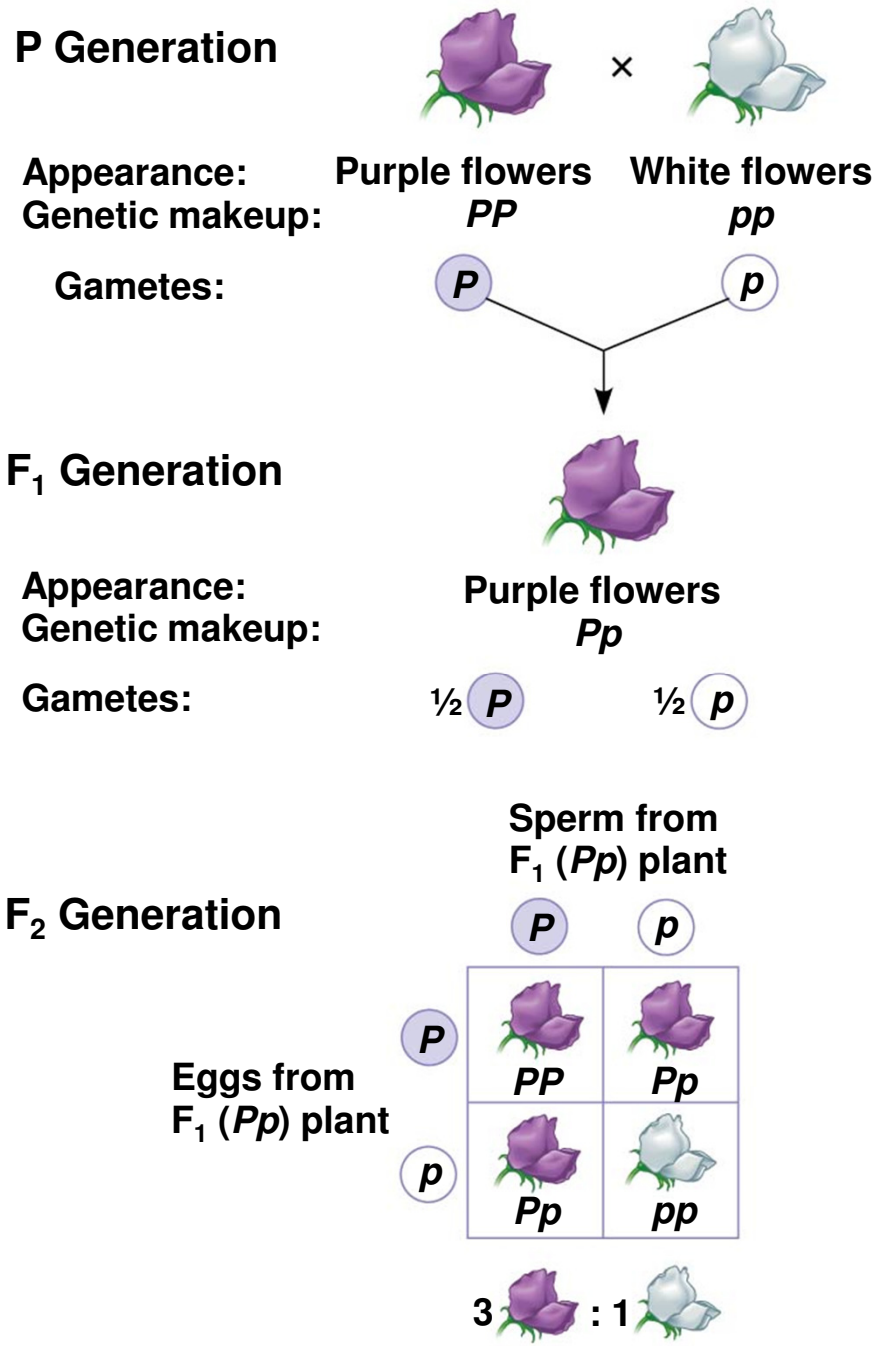
2. Second, *for each character, an organism inherits two alleles, one from each parent*
   - Mendel made this deduction without knowing about the existence of chromosomes
   - Genetic locus is actually represent twice in a diploid cell
     - Once on each homolog of a specific pair of chromosomes
   - Two alleles at a particular locus may be identical, as in the true-breeding plants of Mendel's P generation
   - Alternatively, the two alleles at a locus may differ, as in the F_1 hybrids

3. Third, *if the two alleles at a locus differ, then one (the **dominant allele**) determines the organism's appearance, and the other (the **recessive allele**) has no noticeable effect on appearance*

   - In the flower-color example, the F_1 plants had purple flowers because the allele for that trait is dominant

4. Fourth, *the two alleles for a heritable character separate (segregate) during gamete formation and end up in different gametes*
   - Now known as the **law of segregation**
   - Thus, an egg or a sperm gets only one of the two alleles that are present in the organism
   - This segregation of alleles corresponds to the distribution of homologous chromosomes to different gametes in meiosis

Figure 11.5-3


P Generation
×
Appearance:
Genetic makeup:
Purple flowers
PP
White flowers
pp
Gametes:
P
p
F1 Generation
Appearance:
Genetic makeup:
Purple flowers
Pp
Gametes:
½ P
½ p
Sperm from F1 (Pp) plant
P
p
F2 Generation
Eggs from F1 (Pp) plant
P
p
PP
Pp
Pp
pp
3 : 1

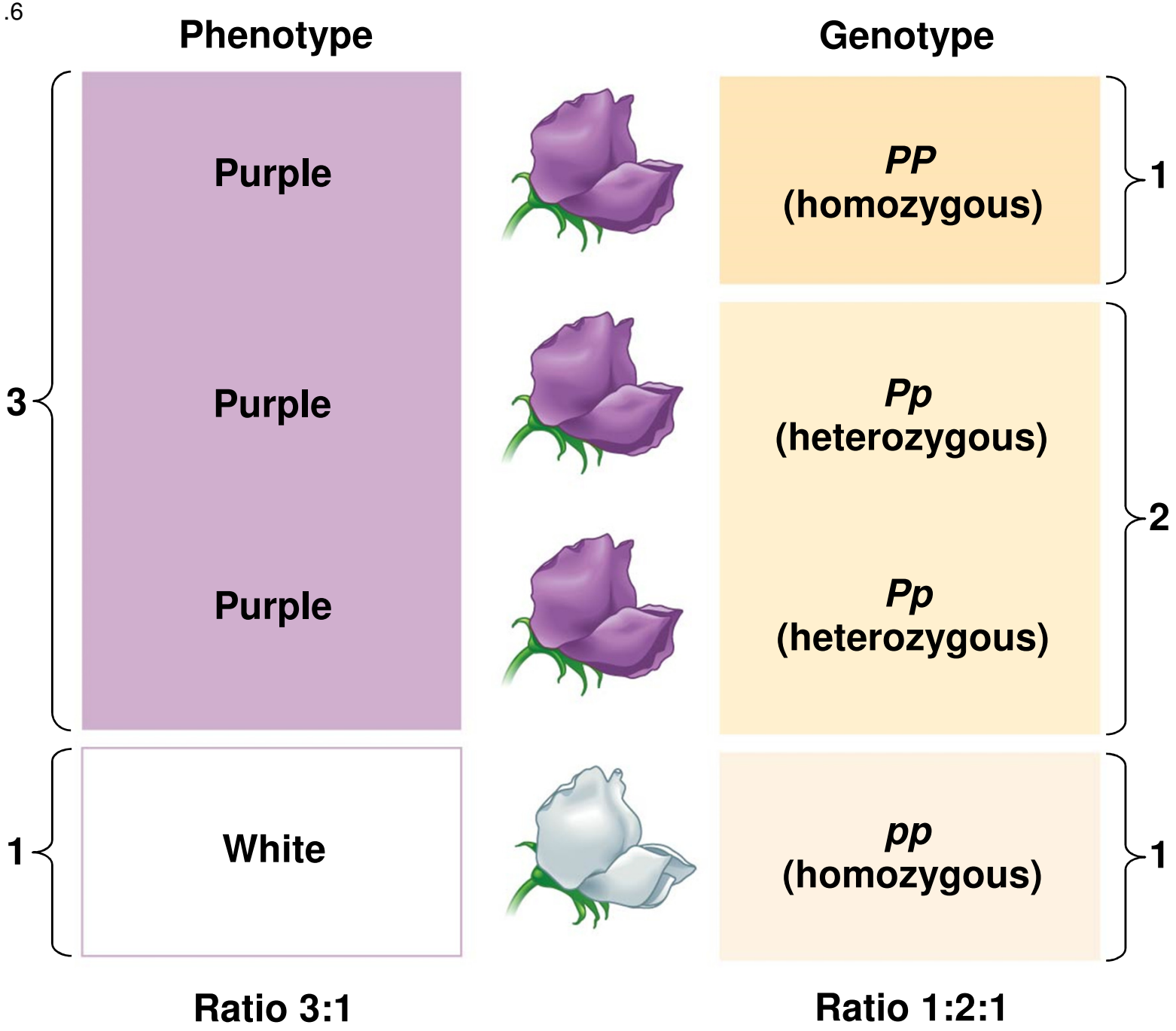
- Mendel's segregation model accounts for the 3:1 ratio he observed in the F_2 generation of his numerous crosses
- The possible combinations of sperm and egg can be shown using a **Punnett square**
  - A diagram for predicting the results of a genetic cross between individuals of known genetic makeup
- A capital letter represents a dominant allele, and a lowercase letter represents a recessive allele
  - For example, *P* is the purple-flower allele
  - And *p* is the white-flower allele

Useful Genetic Vocabulary

- An organism with two identical alleles for a character is said to be **homozygous** for the gene controlling that character
- An organism that has two different alleles for a gene is said to be **heterozygous** for the gene controlling that character
- Unlike homozygotes, heterozygotes are not true-breeding!

- Because of the effects of dominant and recessive alleles, an organism's traits do not always reveal its genetic composition
- Therefore, we distinguish between an organism's **phenotype**, or physical appearance, and its **genotype**, or genetic makeup
  - In the example of flower color in pea plants, *PP* and *Pp* plants have the same phenotype (purple) but different genotypes

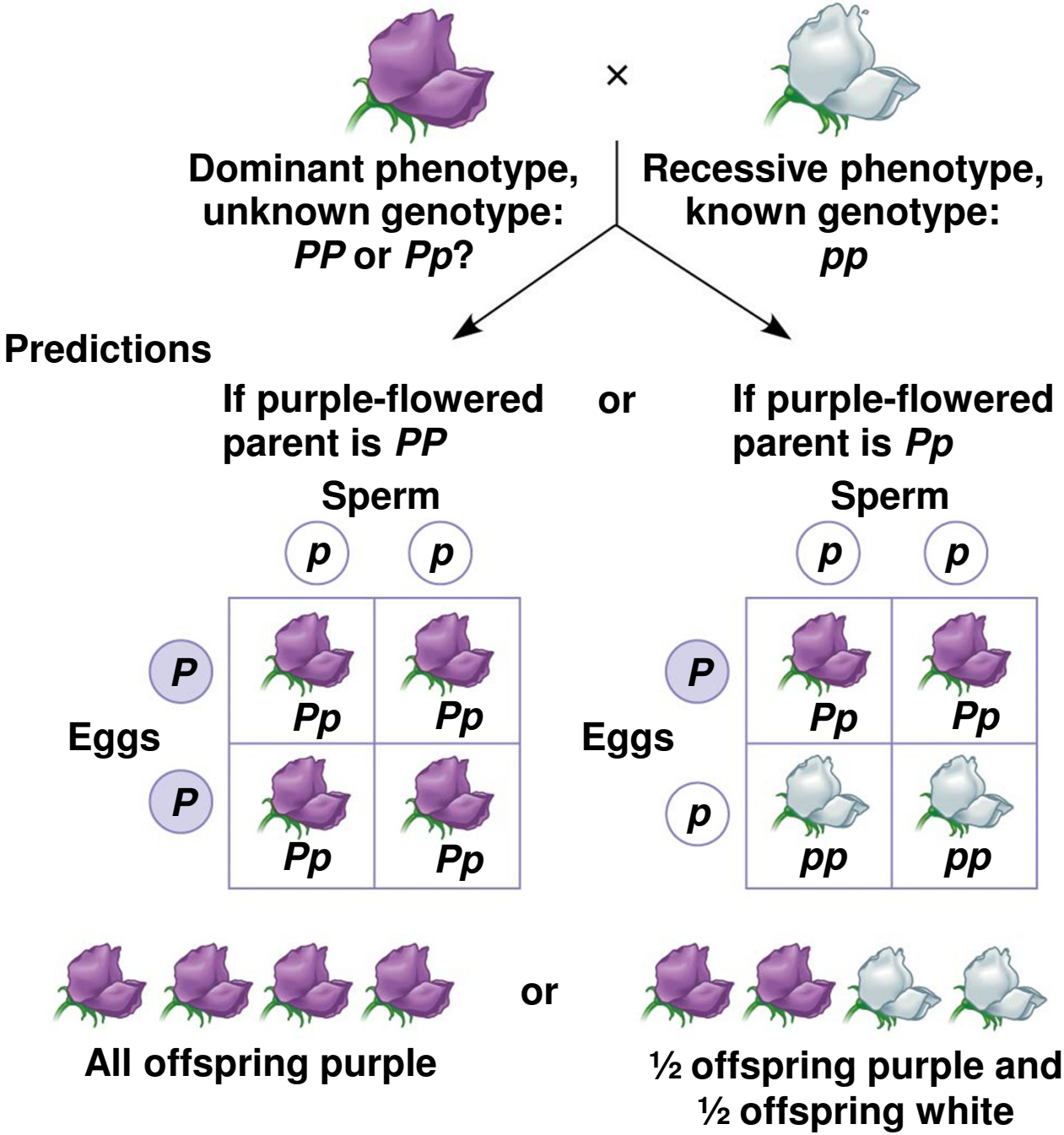
Figure 11.6


Phenotype
Genotype
Purple
Purple
Purple
White
3
1
PP
(homozygous)
Pp
(heterozygous)
Pp
(heterozygous)
pp
(homozygous)
1
2
1
Ratio 3:1
Ratio 1:2:1

The Testcross

- How can we tell the genotype of an individual with the dominant phenotype?
  - Such an individual could be either homozygous dominant or heterozygous
- The answer is to carry out a **testcross**
  - Breeding the mystery individual with a homozygous recessive individual
- If any offspring display the recessive phenotype, the mystery parent must be heterozygous

Figure 11.7


Technique
×
Dominant phenotype, unknown genotype: PP or Pp?
Recessive phenotype, known genotype: pp
Predictions
If purple-flowered parent is PP
or
If purple-flowered parent is Pp
Sperm
p
p
P
P
Eggs
Pp
Pp
Pp
Pp
Sperm
p
p
P
p
Eggs
Pp
Pp
pp
pp
Results
or
All offspring purple
½ offspring purple and ½ offspring white

The Law of Independent Assortment

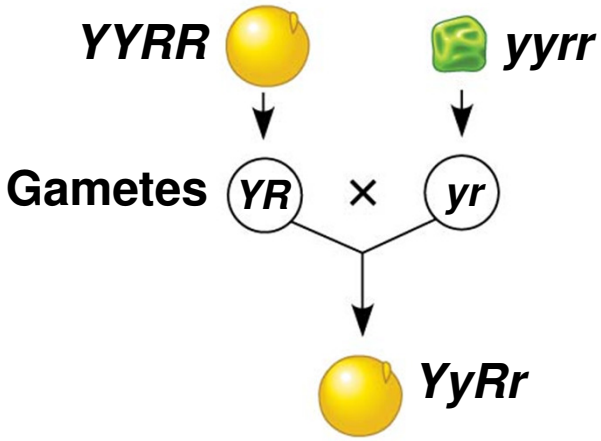
- Mendel derived the law of segregation by following a single character
- The F_1 offspring produced in this cross were **monohybrids**
  - Individuals that are heterozygous for one character
- A cross between such heterozygotes is called a **monohybrid cross**
  - Results in a phenotypic ratio of 3:1

- Mendel identified his second law of inheritance by following two characters at the same time
- Crossing two true-breeding parents differing in two characters produces **dihybrids** in the F_1 generation
  - Heterozygous for both characters
- A **dihybrid cross** is cross between F_1 dihybrids
  - Can determine whether two characters are transmitted to offspring as a package or independently
  - Results in phenotypic ratio of 9:3:3:1

Figure 11.8a

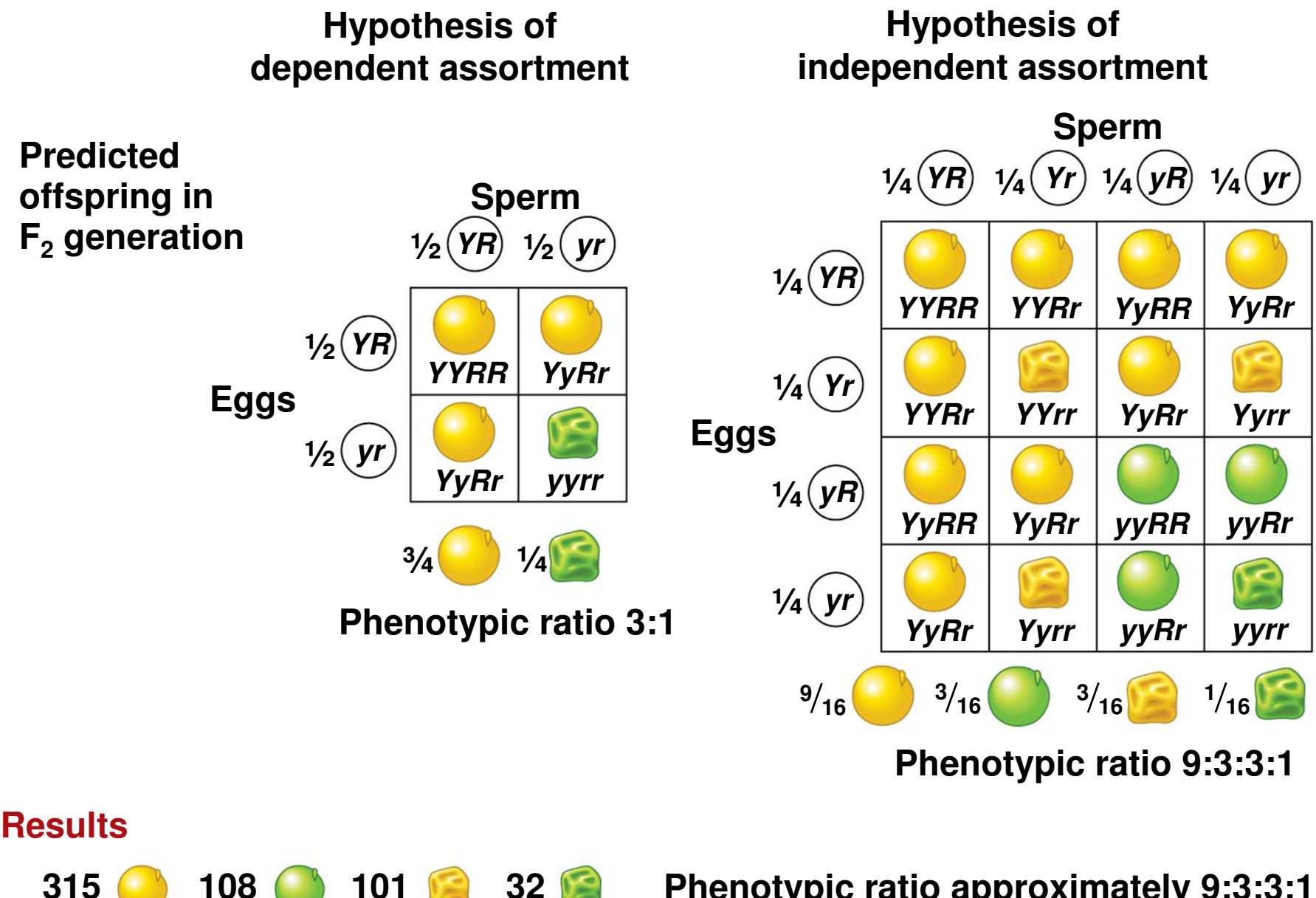
Experiment

P Generation



F_1 Generation

Figure 11.8b



Results

315 108 101 32 Phenotypic ratio approximately 9:3:3:1

- The results of Mendel's dihybrid experiments are the basis for the **law of independent assortment**
  - It states that each pair of alleles segregates independently of each other pair of alleles during gamete formation
- This law applies to genes on different, nonhomologous chromosomes or those far apart on the same chromosome
  - Genes located near each other on the same chromosome tend to be inherited together

Concept 11.2: The laws of probability govern Mendelian inheritance

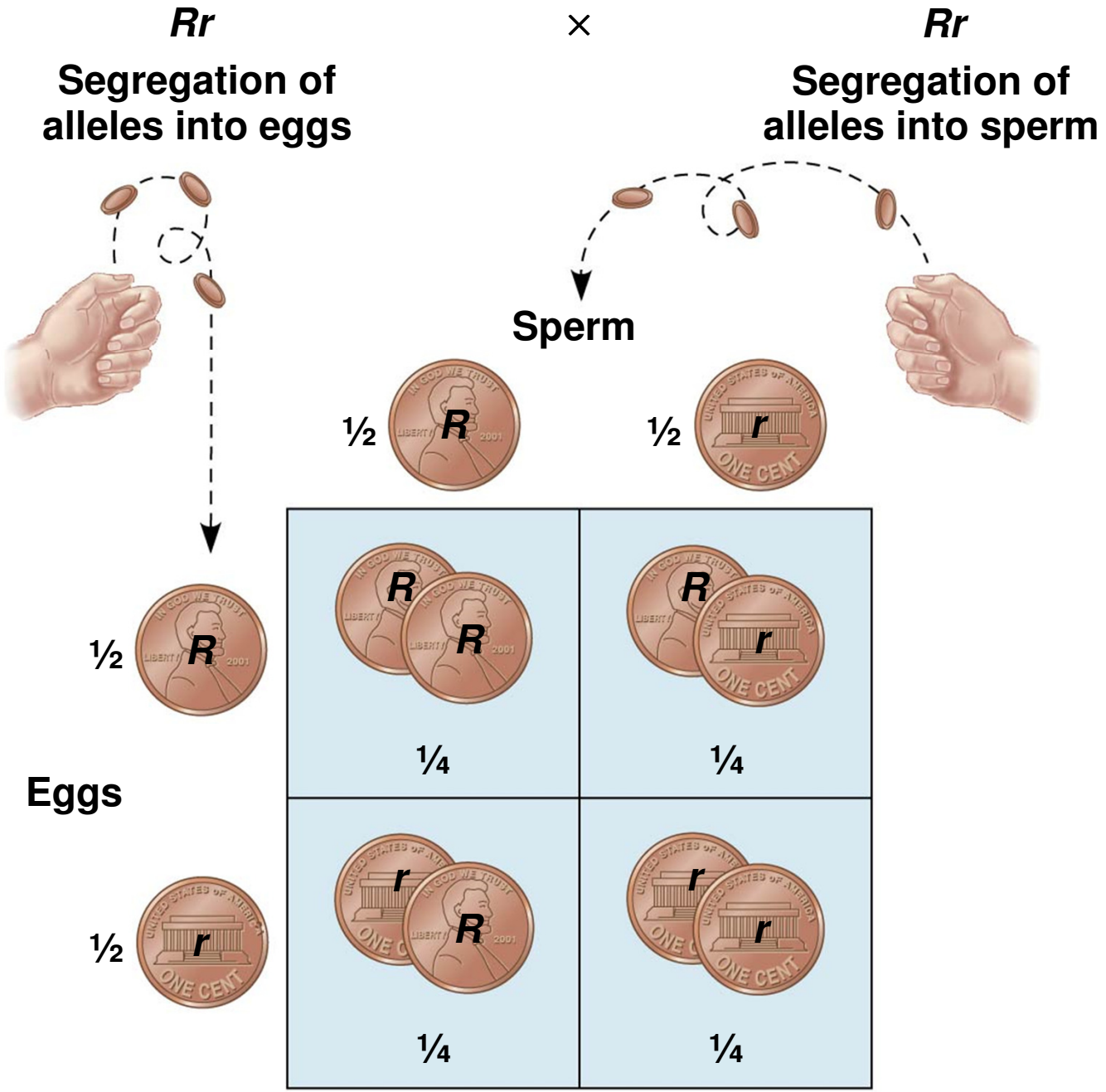
- Mendel's laws of segregation and independent assortment reflect the rules of probability
- When tossing a coin, the outcome of one toss has no impact on the outcome of the next toss
  - Independent events
- In the same way, the alleles of one gene segregate into gametes independently of another gene's alleles

The Multiplication and Addition Rules Applied to Monohybrid Crosses

- The **multiplication rule** states that the probability that two or more independent events will occur together is the product of their individual probabilities
  - Multiply the probability of one event by the probability of the other event
  - Ex: What is the probability that two coins will both land heads up?
    - Probability of heads = ½
    - ½ x ½ = ¼

- This can be applied to an F_1 monohybrid cross
- Segregation in a heterozygous plant is like flipping a coin
  - Each gamete has a ½ chance of carrying the dominant allele
  - And a ½ chance of carrying the recessive allele

Figure 11.9


Rr
×
Rr
Segregation of alleles into eggs
Segregation of alleles into sperm
Sperm
½ R
½ r
Eggs
½ R
½ r
R R
R r
r R
r r
¼
¼
¼
¼

- The **addition rule** states that the probability that any one of two or more mutually exclusive events will occur is calculated by adding together their individual probabilities
- It can be used to figure out the probability that an F_2 plant from a monohybrid cross will be heterozygous rather than homozygous
  - For a heterozygous F_2 plant, the dominant allele can come from the egg OR the sperm, but not from both
    - IE-mutually exclusive
  - ¼ + ¼ = ½

Solving Complex Genetics Problems with the Rules of Probability

- We can apply the rules of probability to predict the outcome of crosses involving multiple characters
- A dihybrid or other multicharacter cross is equivalent to two or more independent monohybrid crosses occurring simultaneously
- In calculating the chances for various genotypes, each character is considered separately, and then the individual probabilities are multiplied

- For example, if we cross F_1 heterozygotes of genotype *YyRr*, we can calculate the probability of different genotypes among the F_2 generation
  - Probability of YYRR
    - ¼ (Probability of YY) x ¼ (RR) = 1/16
  - Probability of YyRR
    - ½ (Yy) x ¼ (RR) = 1/8

- For example, for the cross *PpYyRr* × *Ppyyrr,* we can calculate the probability of offspring showing at least two recessive traits
  - ppyyRr = ¼ (pp) x ½ (yy) x ½ (Rr) = 1/16
  - ppYyrr = ¼ x ½ x ½ = 1/16
  - Ppyyrr = ½ x ½ x ½ = 2/16
  - PPyyrr = ¼ x ½ x ½ = 1/16
  - ppyyrr = ¼ x ½ x ½ = 1/16
  - Added together = 6/16 or 3/8

Concept 11.3: Inheritance patterns are often more complex than predicted by simple Mendelian genetics

- Not all heritable characters are determined as simply as the traits Mendel studied
- However, the basic principles of segregation and independent assortment apply even to more complex patterns of inheritance

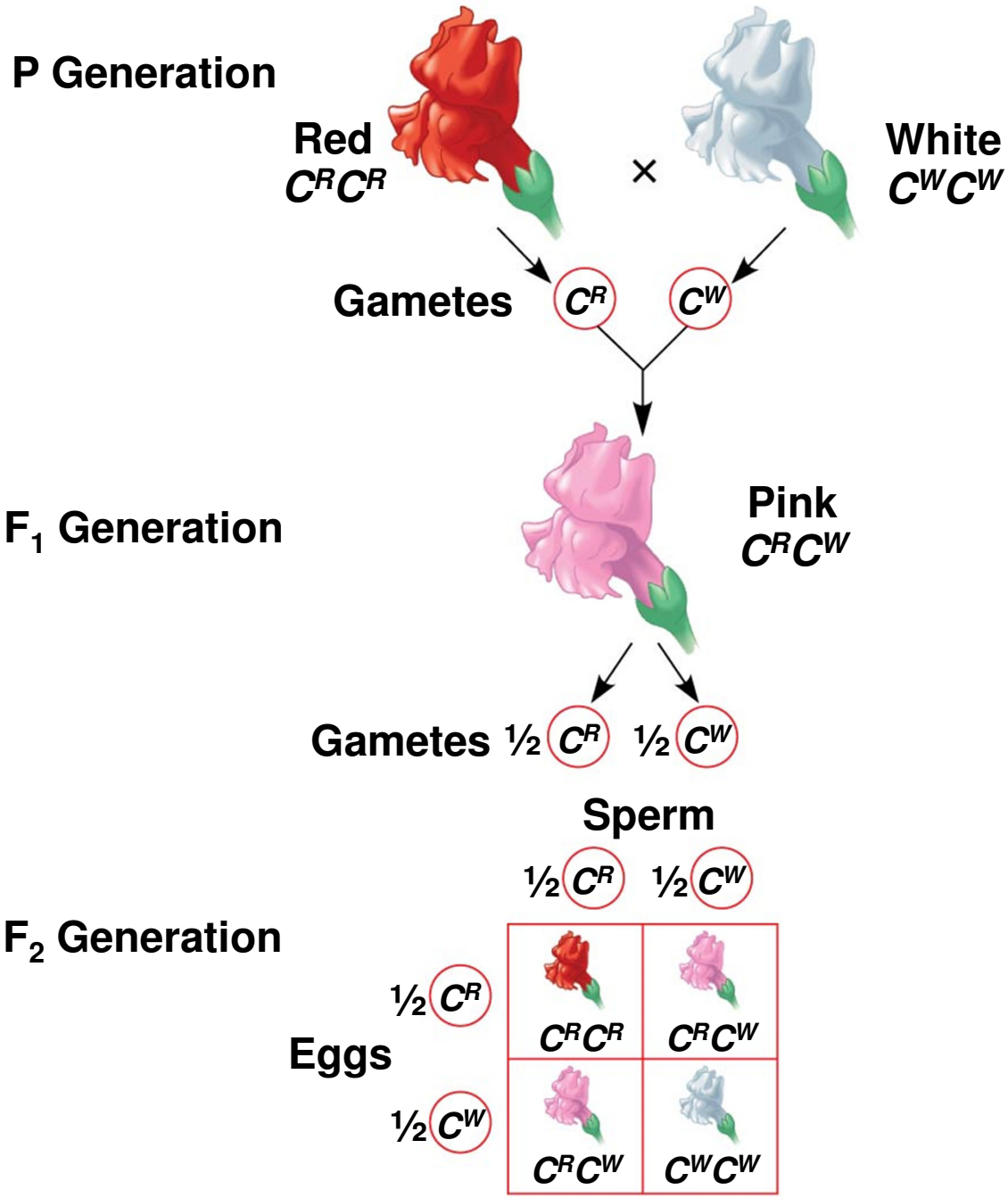
Extending Mendelian Genetics for a Single Gene

- Inheritance of characters by a single gene may deviate from simple Mendelian patterns in the following situations
  - When alleles are not completely dominant or recessive
  - When a gene has more than two alleles
  - When a single gene influences multiple phenotypes

Degrees of Dominance

- **Complete dominance** occurs when phenotypes of the heterozygote and dominant homozygote are identical
- In **incomplete dominance**, the phenotype of heterozygote is an intermediate somewhere between the phenotypes of the two parental varieties
  - Ex: Flower color in snapdragons
    - RR = Red, WW = White, RW = Pink
- In **codominance**, the phenotypes of both alleles are fully expressed in the heterozygote
  - Ex: Coat color in cattle
    - RR = Red, WW = White, RW = Roan (Red AND White)

Figure 11.10-3



The Relationship Between Dominance and Phenotype

- Alleles are simply variations in a gene's nucleotide sequence
- When a dominant allele coexists with a recessive allele in a heterozygote, they do not actually interact at all
  - It is in the pathway from genotype to phenotype that dominance and recessiveness come into play

- Ex: Round vs wrinkled pea seeds
  - Dominant allele codes for enzyme that converts starch from unbranched to branched
  - Recessive allele codes for defective form of enzyme, leading to more unbranched starch
    - Causes extra water to enter seed
    - Seed wrinkles when it dries
  - One dominant allele results in enough enzyme synthesizing branched starch
    - Both the dominant homozygote and heterozygote have the same phenotype of round seeds

- For any character, dominant/recessive relationships of alleles depend on the level at which we examine the phenotype
- **Tay-Sachs disease** is a fatal disorder resulting from a dysfunctional enzyme causing an accumulation of lipids in the brain
  - At the *organismal* level, the allele is recessive
  - At the *biochemical* level, the phenotype (i.e., the enzyme activity level) is incompletely dominant
  - At the *molecular* level, the alleles are codominant

Frequency of Dominant Alleles

- Dominant alleles are not necessarily more common in populations than recessive alleles
  - Ex: One baby out of 400 in the United States is born with extra fingers or toes, a dominant trait called polydactyly

Multiple Alleles

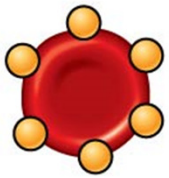
- Most genes exist in populations in more than two allelic forms
- For example, the four phenotypes of the ABO blood group in humans are determined by three alleles of the gene: I^A, I^B, and i.
- The enzyme (I) adds specific carbohydrates to the surface of blood cells
  - I^A adds the A carbohydrate
  - I^B adds the B carbohydrate
  - i allele adds neither

Figure 11.11

(a) The three alleles for the ABO blood groups and their carbohydrates

Allele	I^A	I^B	i
Carbohydrate	A 	B 	none

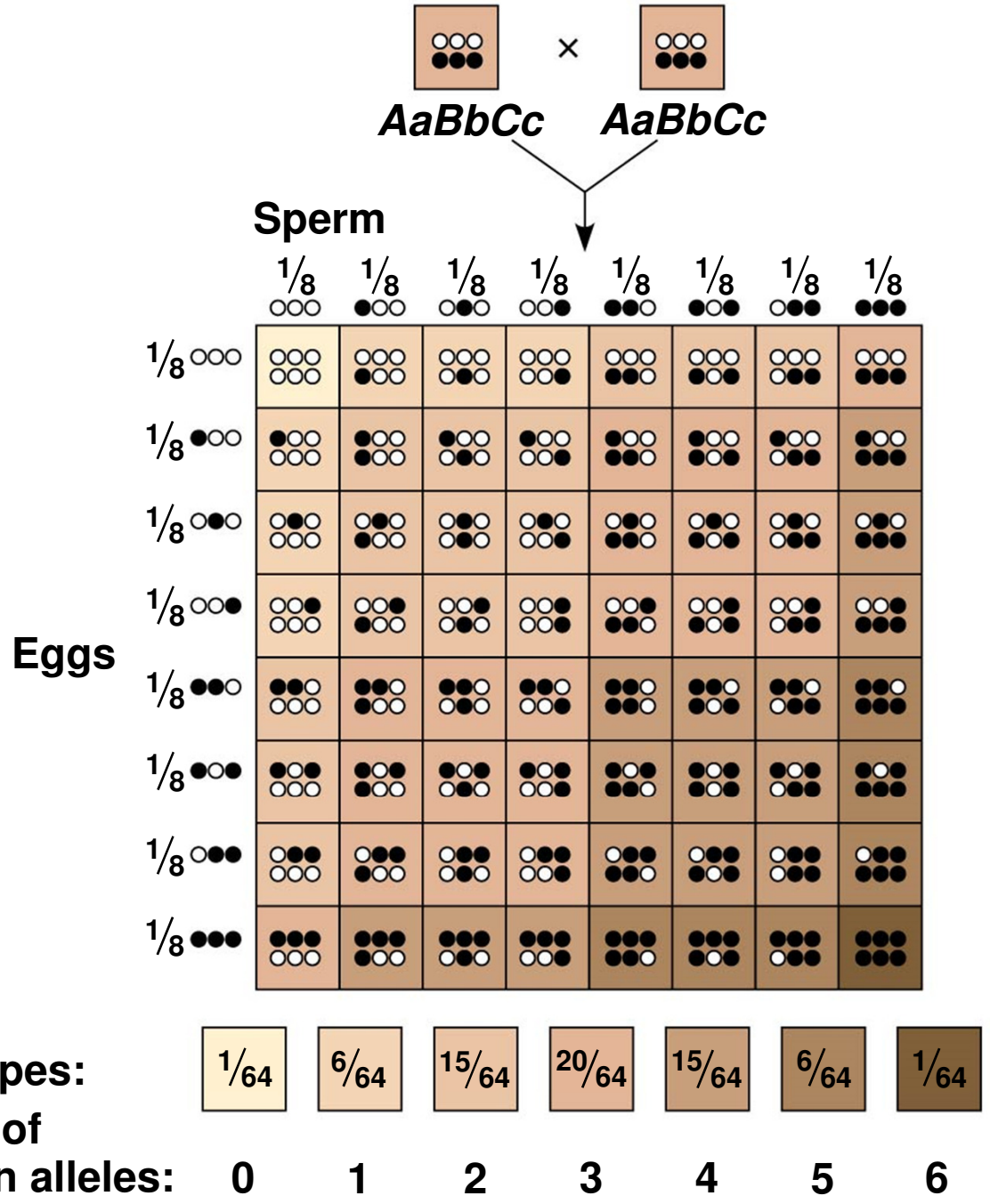
(b) Blood group genotypes and phenotypes

Genotype	I^AI^A or I^Ai	I^BI^B or I^Bi	I^AI^B	ii
Red blood cell appearance				
Phenotype (blood group)	A	B	AB	O

Extending Mendelian Genetics for Two or More Genes

- Some traits may be determined by two or more genes
- **Quantitative characters** are those that vary in the population along a continuum
- Quantitative variation usually indicates **polygenic inheritance**
  - An additive effect of two or more genes on a single phenotype
- Skin color in humans is an example of polygenic inheritance
  - Note: Environmental factors, such as sun exposure, can also affect skin-color phenotype

Figure 11.13


AaBbCc
×
AaBbCc
Sperm
1/8
Eggs
Phenotypes:
1/64
6/64
15/64
20/64
15/64
6/64
1/64
Number of dark-skin alleles:
0
1
2
3
4
5
6

Nature and Nurture: The Environmental Impact on Phenotype

- Another departure from Mendelian genetics arises when the phenotype for a character depends on environment as well as genotype
- The phenotypic range is generally broadest for polygenic characters
- Such characters are called **multifactorial** because genetic and environmental factors collectively influence phenotype

Integrating a Mendelian View of Heredity and Variation

- An organism's phenotype includes its physical appearance, internal anatomy, physiology, and behavior
- An organism's phenotype reflects its overall genotype and unique environmental history

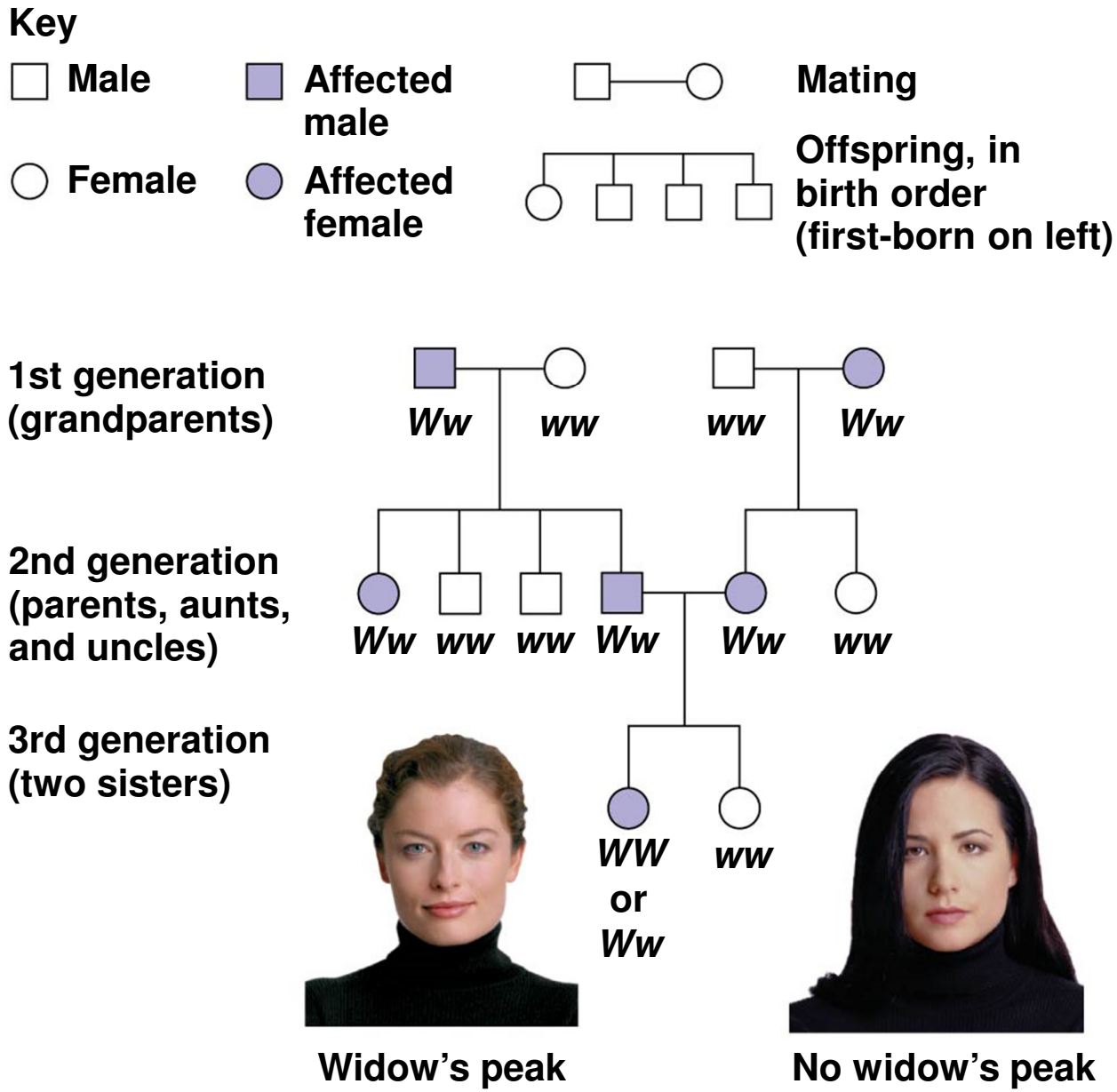
Concept 11.4: Many human traits follow Mendelian patterns of inheritance

- Humans are not good subjects for genetic research
  - Generation time is too long
  - Parents produce relatively few offspring
  - Breeding experiments are unacceptable
- However, basic Mendelian genetics endures as the foundation of human genetics

Pedigree Analysis

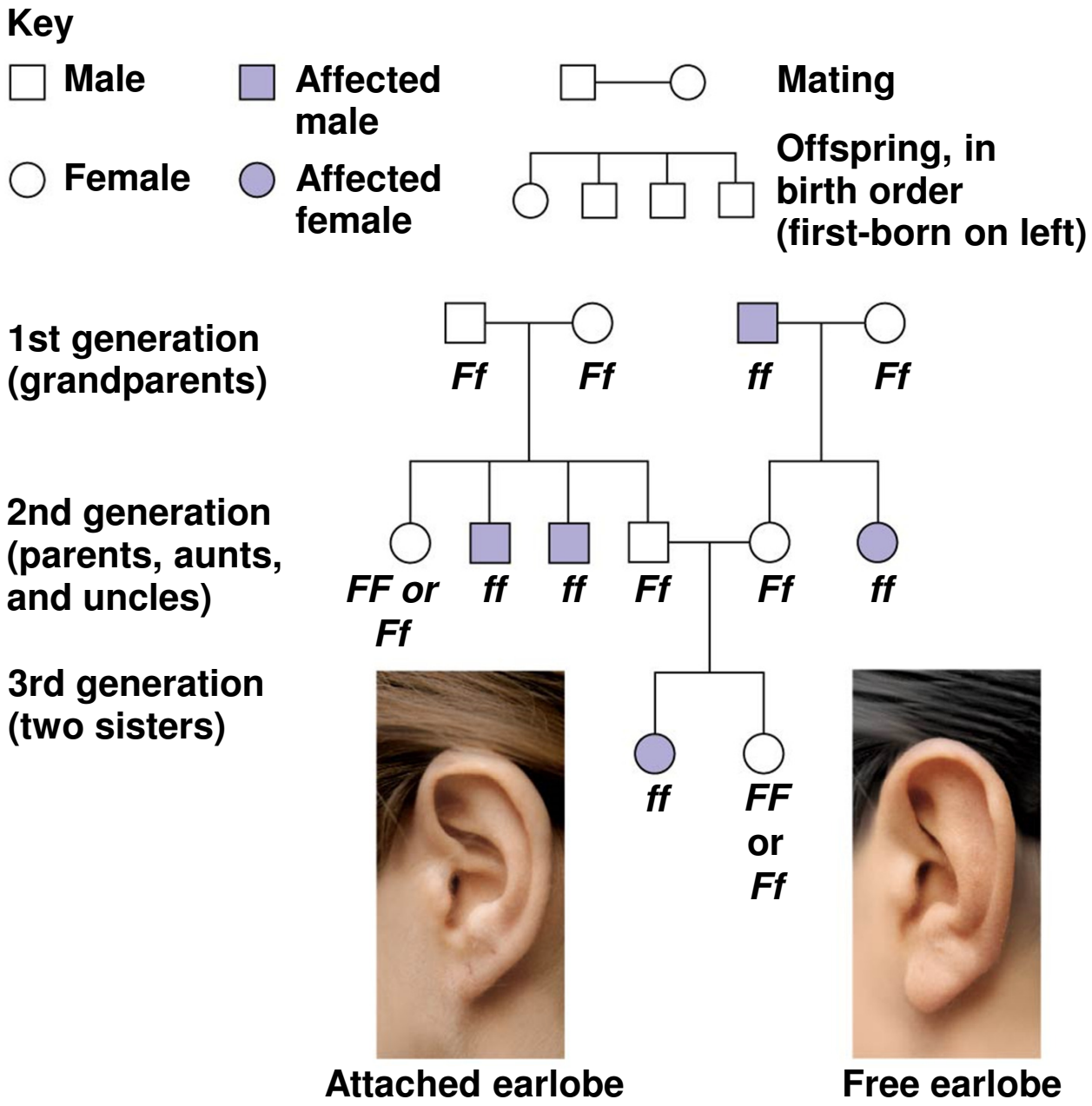
- A **pedigree** is a family tree that describes the interrelationships of parents and children across generations
- Inheritance patterns of particular traits can be traced and described using pedigrees
- Pedigrees can also be used to make predictions about future offspring
- We can use the multiplication and addition rules to predict the probability of specific phenotypes

Figure 11.14a



(a) Is a widow's peak a dominant or recessive trait?

Figure 11.14b

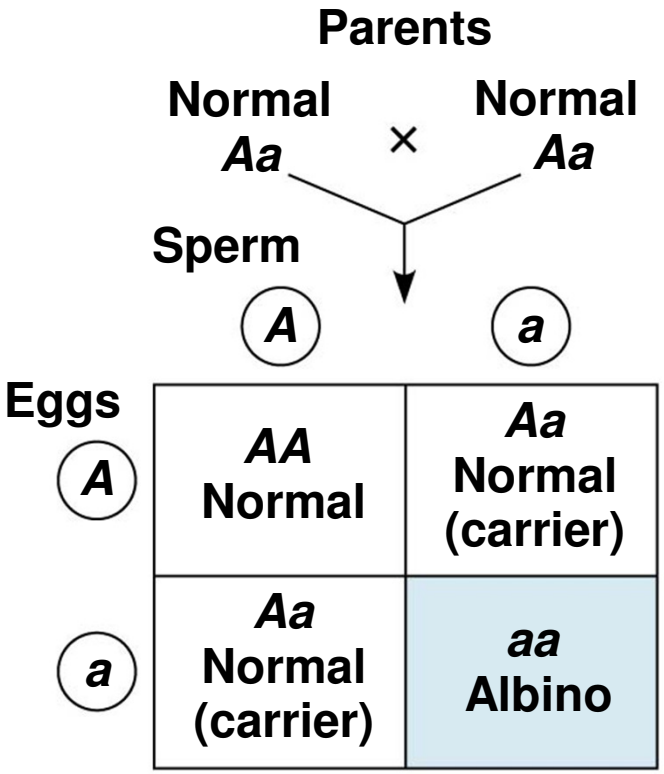


(b) Is an attached earlobe a dominant or recessive trait?

Recessively Inherited Disorders

- Many genetic disorders are inherited in a recessive manner
- These range from relatively mild to life-threatening
- Recessively inherited disorders show up only in individuals homozygous for the allele
- **Carriers** are heterozygous individuals who carry the recessive allele but are phenotypically normal
  - Most people who have recessive disorders are born to parents who are carriers of the disorder

Figure 11.15


Parents
Normal
Aa
×
Normal
Aa
Sperm
A
a
Eggs
A
AA
Normal
Aa
Normal
(carrier)
a
Aa
Normal
(carrier)
aa
Albino

- If the disorder is lethal before reproductive age or results in sterility, no homozygous individuals will reproduce
- If a recessive allele that causes a disease is rare, then the chance of two carriers meeting and mating is low
- Consanguineous (between close relatives) matings increase the chance of mating between two carriers of the same rare allele

Cystic Fibrosis

- **Cystic fibrosis** is the most common lethal genetic disease in the United States,striking one out of every 2,500 people of European descent
- The cystic fibrosis allele results in defective or absent chloride transport channels in plasma membranes leading to a buildup of chloride ions outside the cell
- Symptoms include mucus buildup in some internal organs and abnormal absorption of nutrients in the small intestine

Sickle-Cell Disease: A Genetic Disorder with Evolutionary Implications

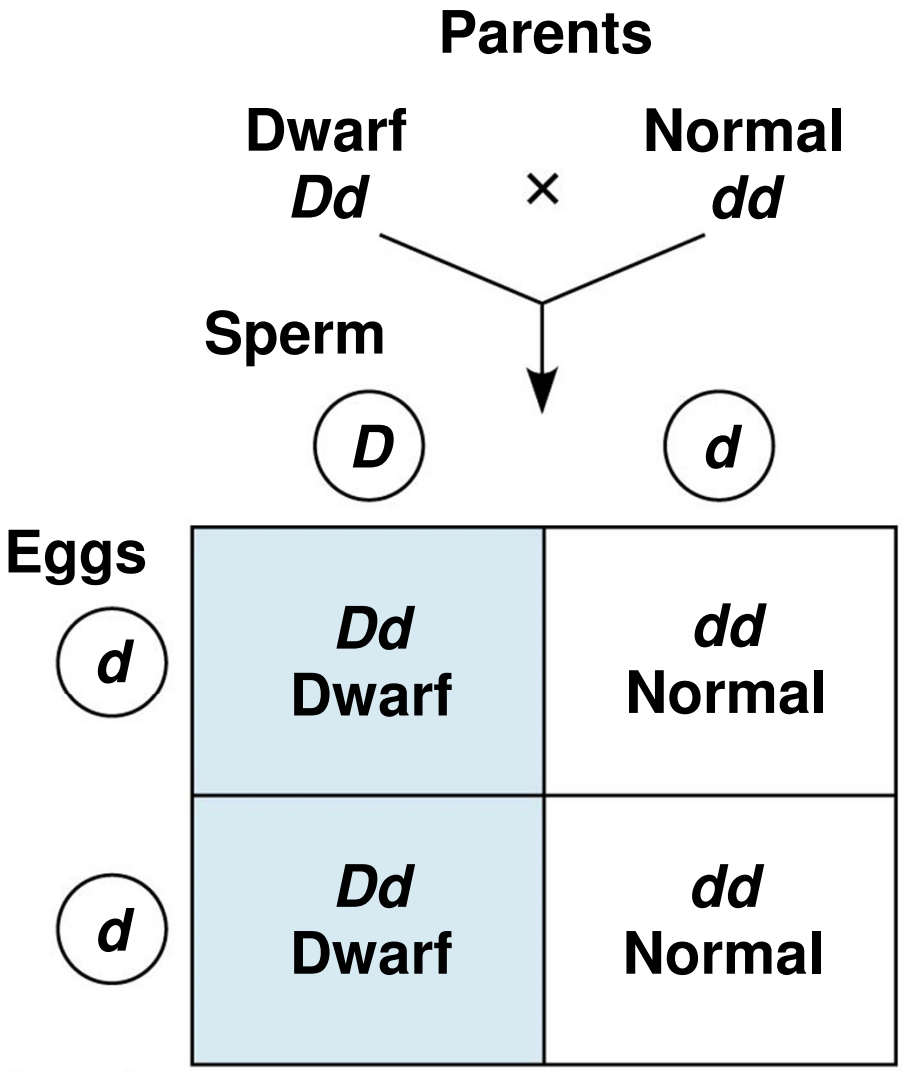
- **Sickle-cell disease** affects one out of 400 African-Americans
- The disease is caused by the substitution of a single amino acid in the hemoglobin protein in red blood cells
- In homozygous individuals, all hemoglobin is abnormal (sickle-cell)
- Symptoms include physical weakness, pain, organ damage, and even paralysis

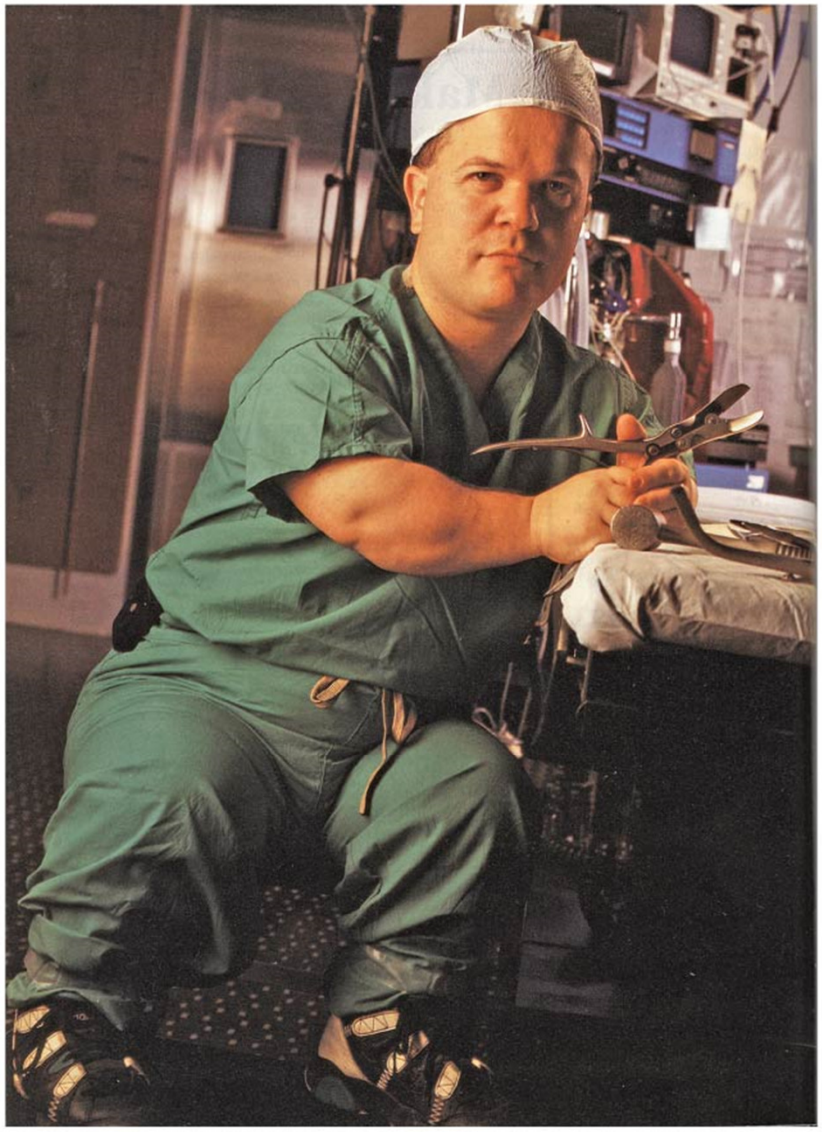
- Heterozygotes (said to have sickle-cell trait) are usually healthy but may suffer some symptoms
  - Organismal level: Normal allele is incompletely dominant to sickle cell allele
    - Presence of one sickle-cell allele can affect phenotype
  - Molecular level: Two alleles are codominant
    - Both normal and abnormal hemoglobins are made
- About one out of ten African-Americans has sickle-cell trait, an unusually high frequency of an allele with detrimental effects in homozygotes
- Heterozygotes are less susceptible to the malaria parasite, so there is an advantage to being heterozygous

Dominantly Inherited Disorders

- Some human disorders are caused by dominant alleles
  - Ex: Achondroplasia, a form of dwarfism
- Dominant alleles that cause a lethal disease are rare and arise by mutations in cells that produce eggs or sperm
  - Note: Lethal recessive alleles can be passed on by carriers
  - But lethal dominant alleles often cause death of individuals before they can reproduce

Figure 11.16


Parents
Dwarf
Dd
×
Normal
dd
Sperm
D
d
Eggs
d
Dd
Dwarf
dd
Normal
d
Dd
Dwarf
dd
Normal



- The timing of onset of a disease significantly affects its inheritance
- **Huntington's disease** is a degenerative disease of the nervous system
  - The disease has no obvious phenotypic effects until the individual is about 35 to 45 years of age
- Once the deterioration of the nervous system begins the condition is irreversible and fatal

Multifactorial Disorders

- Many diseases, such as heart disease, diabetes, alcoholism, mental illnesses, and cancer, have both genetic and environmental components
- Lifestyle has a tremendous effect on phenotype for cardiovascular health and other multifactorial characters

Genetic Counseling Based on Mendelian Genetics

- Genetic counselors can provide information to prospective parents concerned about a family history for a specific disease
- Each child represents an independent event in the sense that its genotype is unaffected by the genotypes of older siblings